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Predictive System of the Water Deficit Analysis for the Black Sea Lowland (an example of the Kherson Region)

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***Abstract*— Developing a predictive system for water deficit analysis in the Black Sea Lowland, especially in climate change, involves integrating various data sources, modeling techniques, and technological tools to forecast water availability and demand.**

The analysis of the change in moisture deficit in the Kherson region is provided for the period from 1955 to 2022. The description of with temperature gradients across the Kherson region is provided. The distribution of precipitation throughout the years in terms of quantity and intensity is provided.

As part of the Black Sea Lowland, the Kherson region is critically important for southern Ukraine's agriculture and water security. Given the region's reliance on irrigation and the challenges posed by climate change, developing a predictive system for water deficit analysis is essential. Such a system can help stakeholders make informed decisions to ensure sustainable water management and mitigate the adverse effects of water scarcity.

***Index Terms*— predictive system, water deficit, climate change, the Kherson region, lack of moisture, weather stations, precipitation**

I. Introduction

As PART of the Black Sea Lowland, the Kherson region is critically important for southern Ukraine's agriculture and water security. Given the region's reliance on irrigation and the challenges posed by climate change, developing a predictive system for water deficit analysis is essential [1-5].

The Kherson region is a major agricultural hub, producing significant quantities of grains, vegetables, and fruits, which rely heavily on irrigation. Agriculture is a key economic driver, contributing significantly to the local and national economies. Ensuring water availability for agriculture is crucial for food security and economic stability [6].

The Dnieper River and associated canals (e.g., the North Crimean Canal) are primary water sources for irrigation and municipal use. Groundwater resources are also vital, though their overuse can lead to depletion and degradation, impacting long-term water availability [7-11].

Rising temperatures lead to higher evaporation rates, reducing water availability. This can exacerbate water shortages, especially during peak agricultural periods [12–17].

Changes in precipitation patterns, with more frequent droughts and irregular rainfall, affect water supply consistency. Unpredictable weather patterns make it difficult to plan for water usage effectively [17-19].

Due to increasing water demand for irrigation due to intensive farming practices efficient water management becomes crucial to sustain agricultural productivity [3]..

Growing population and industrial activities further strain water resources. Ensuring an adequate supply of water for all sectors is essential to support regional development [19].

Therefore a need for a predictive system of the water deficit analysis, which can provide early warnings of potential water shortages, allowing for proactive management and planning. This can help in preparing for droughts and other extreme events. Also, it helps in devising strategies to mitigate risks associated with water scarcity, such as crop failure and economic losses.

II. Methods and Techniques

It is proposed the structured approach to designing the predictive system for water deficit analysis consists of the following steps :

1. Data Collection and Integration:
   1.1. Climate data - collect historical data on temperature, precipitation, humidity, and wind patterns.
   1.2. Hydrological data:
   - River flows: data on river discharge rates, particularly for major rivers like the Dnipro River;
   - Reservoir levels: historical and current water levels in reservoirs and major water bodies;
   - Groundwater levels: data from groundwater monitoring wells.

   1.3. Water Usage Data:
   - Agricultural Demand: Information on crop types, irrigation practices, and water usage patterns;
   - Domestic and Industrial Use: Data on municipal and industrial water consumption.
2. Modeling Framework:
   2.1. Climate models - apply regional climate models to downscale global climate projections to the Black Sea Lowland region for more accurate local predictions.
   2.2. Hydrological models:

- Rainfall-runoff models - use models like SWAT (Soil and Water Assessment Tool) to simulate the conversion of rainfall to runoff and river flow;
- Water balance models - implement models that account for inputs (precipitation, river inflows) and outputs (evaporation, water extraction) to estimate water availability.

2.3. Demand models:

- Agricultural demand - develop models to estimate future irrigation needs based on crop types, planting schedules, and climate conditions;
- Municipal and Industrial demand - use demographic and economic projections to forecast changes in water demand for domestic and industrial uses.

3. System Design:

3.1. Data integration platform:

- GIS integration - use a Geographic Information System (GIS) to integrate spatial data on climate, hydrology, and land use;
- Database Management - implement robust databases to store and manage large volumes of data from various sources.

3.2. Predictive Analytics / Scenario Analysis - develop tools to simulate different scenarios (e.g., varying levels of water usage, different climate change scenarios) and assess their impact on water deficit.

4. Application and Use Cases:

4.1. Agricultural planning:

- Crop planning - assist farmers in planning crop types and irrigation schedules based on predicted water availability;
- Water allocation - help water managers allocate water resources efficiently during dry periods.

4.2. Urban and industrial water management:

- Demand management - support municipalities and industries in managing water demand and implementing conservation measures;
- Infrastructure planning - guide investment in water infrastructure, such as reservoirs and pipelines, to mitigate future water deficits.

To characterize the climatic features of the object, data from the weather stations Askania-Nova, Velyka Oleksandrivka, Kherson, Nova-Kakhovka, Nizhny Sirogozy, Khorly (Fig. 1.) and the relevant sources were used [20-25] .

Fig. 1. Scheme of the map of the Kherson region and the location of weather stations: 1 – Kherson; 2 – Velyka Oleksandrivka; 3 – Askania-Nova; 4 – Nova Kakhovka; 5 – Nizhny Sirogozy; 6 - Khorly.

III. RESULTS AND DISCUSSION

According to the Köppen climate classification [20-22], the classification of climates Alisova et al. [23-25] this territory belongs to the Black Sea sub-region of the Atlantico-continental steppe region. The climate is typically continental with a high heat resource and insufficient humidity.

The change of seasons occurs gradually without sharp temperature fluctuations, the average annual air temperature ranged from 8.1°C (1976) to 11.4°C (1966), with an average annual value of 9.7°C. The coldest month is January, with an average monthly temperature ranging from -11.2°C (1972) to 1.9°C (1966) and an average annual value of -3.5°C. The winter period does not exceed 100 days. Winter is short, moderately cold, mild, with frequent thaws. The snow cover usually appears in November-December, characterized by instability, and melts in February-March.

The snow depth does not exceed 5-10 cm. Snow is not the main source of spring moisture accumulation in the soil in this area. The instability of the temperature regime is due to frequent soil thawing in winter, affecting soil moisture in the aeration zone during the winter period.

The spring increase in average daily temperature in March leads to the complete thawing of the frozen layer. The increase in evaporation of moisture in spring, along with rising air temperatures, causes a sharp increase in moisture deficit. The warmest month is July, with an average monthly air temperature ranging from 20.5°C (1969) to 24.3°C (1972) and an average annual value of 23.2°C.

By the degree of humidity, the northern and central parts of the territory belong to the zone of insufficient humidity with a humidity coefficient greater than 0.5 (for Askania-Nova - 0.68), while the southern part (Prisivashshya) belongs to the coastal arid zone with a humidity coefficient of approximately 0.4. The annual precipitation varied from 238.5 mm (1984) to 640.8 mm (1966). According to the book "Climate of Ukraine," on average in the northern hemisphere, the surface air temperature increased by only 0.5°C from 1961-1990, and globally by 0.4°C. The change in annual temperature over a 100-year period in the Steppe region is 0.2-0.3°C towards warming. Winter warming is 1.2°C, in spring - 0.8°C, with minor changes in summer and autumn.

From 1900 to 2020, the annual amount of precipitation in Ukraine varied unevenly. In some regions, there was an increase in precipitation by 7-10% (over 40 mm) from the climatological norm, while in the rest of the territory, it remained within the norm. During the period of maximum global warming, starting from 1975, a decrease in the amplitude of precipitation fluctuations from year to year was observed almost throughout Ukraine. This means that the moisture regime stabilized and is within the climatological norm. It is known that seasonal unevenness in precipitation, an increase in average annual precipitation in recent decades, and the amplitude of precipitation in certain years are natural factors contributing to flooding.

The distribution of precipitation throughout the year is uneven both in quantity and intensity. The highest amount of precipitation falls during dry months when evaporation is high. Summer rainfall (35-40% of the annual total) occurs in the form of short downpours and heavy rains, often accompanied by thunderstorms. The main spatial distribution pattern of precipitation in Ukraine, determined by general circulation factors, is their decrease from the northwest to the southeast.

In the Kherson region, the average annual precipitation decreases from 450 to 300 mm and less from northwest to southeast, reaching 230 mm on the coast of the seas. The distribution of precipitation throughout the year is uneven both in quantity and intensity. The highest amount of precipitation falls during dry months when evaporation is high. Summer rainfall (35-40% of the annual total) occurs in the form of short downpours and heavy rains, often accompanied by thunderstorms. The most significant increase in precipitation is observed in the observation zone of the Kherson and Velyka Oleksandrivka weather stations, with slightly less growth in the observation zone of Nova Kakhovka and Nyzhni Sirohozy weather stations, and very slight increase in the observation zone of Askania-Nova and Khorly weather stations.

An analysis of the long-term dynamics of precipitation at the Kherson and Velyka Oleksandrivka weather stations was conducted for the periods 1955-1975, 1976-1995, and 1996-2022. Comparison of the long-term seasonal unevenness of precipitation at the Kherson weather station indicates a gradual increase in the average precipitation over twenty years, especially in the last forty-five years (41 mm), indicating a gradual increase in overall natural loading. In the winter period (most critical for replenishing groundwater with atmospheric precipitation), the overall increase in average precipitation was 21 mm, while in the summer period, precipitation increased by 19 mm (Fig. 2).

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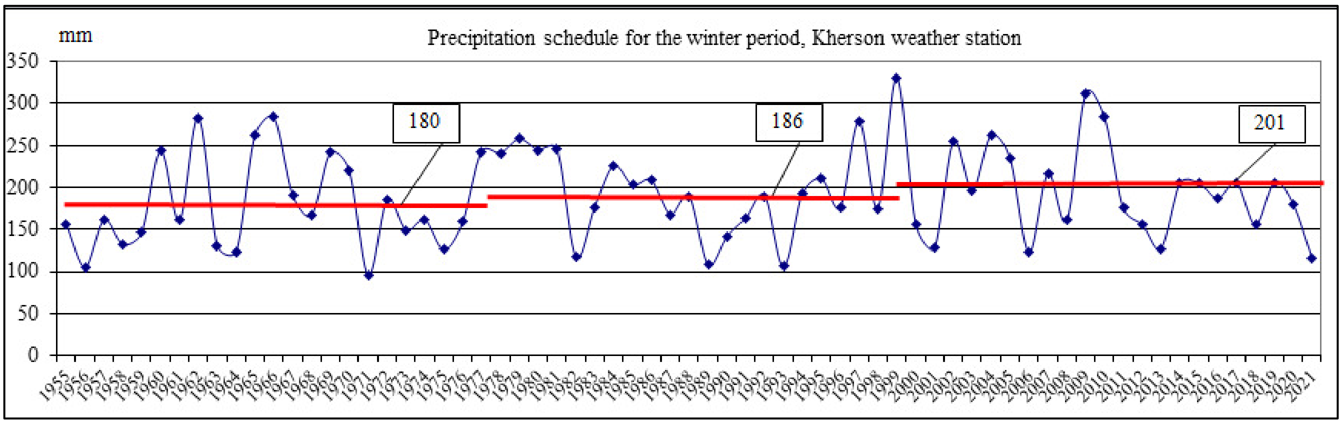

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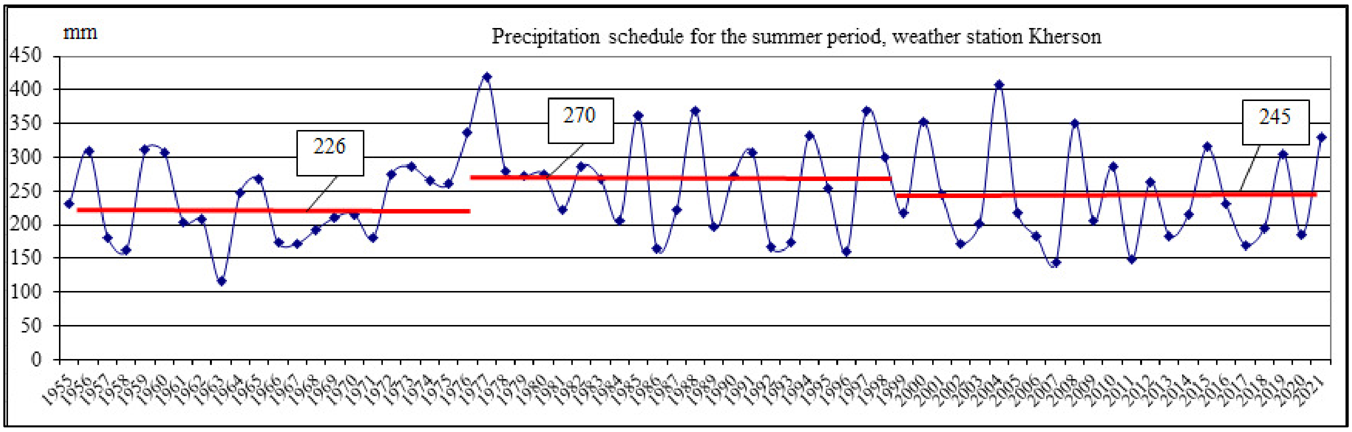

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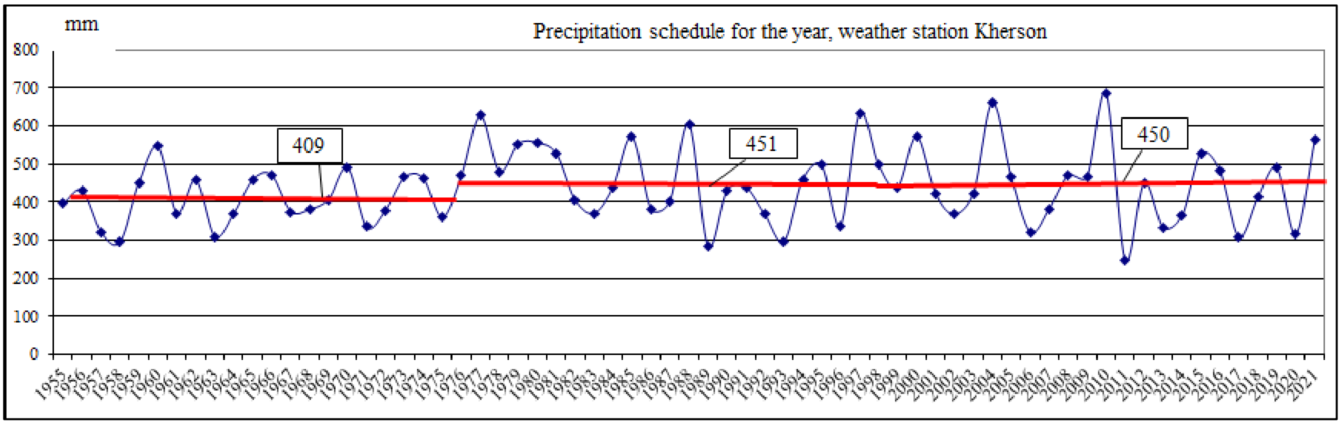

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Fig. 2. Precipitation schedule according to Kherson weather station data:
a) winter period; b) summer period; c) for a year.

A comparison of the long-term seasonal unevenness of precipitation at the Velyka Oleksandrivka weather station was carried out in a similar way (Fig. 3). The analysis shows a gradual increase in the average rainfall over sixty-five years (44 mm), which indicates a significant increase in the total natural load. Moreover, in the winter period (the most threatening, in terms of replenishment of groundwater by atmospheric precipitation), the total increase in average precipitation was 8 mm, in the summer period precipitation increased by 48 mm.

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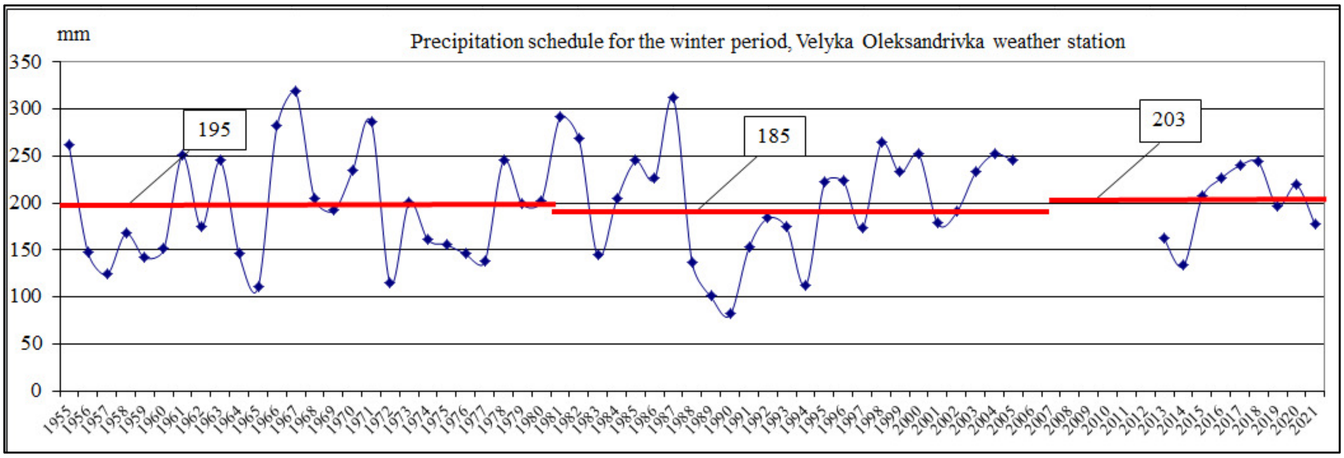

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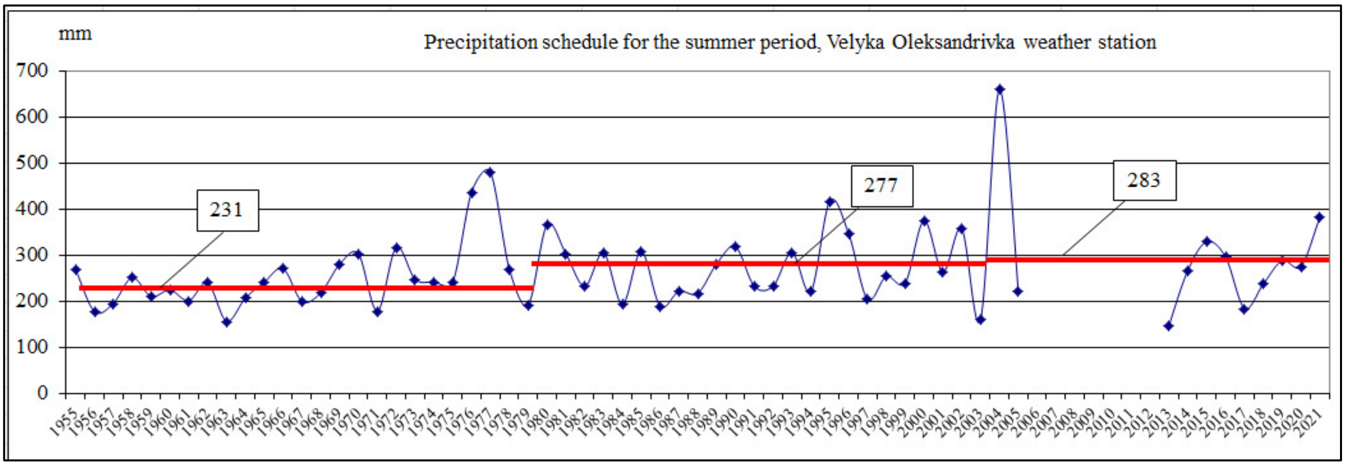

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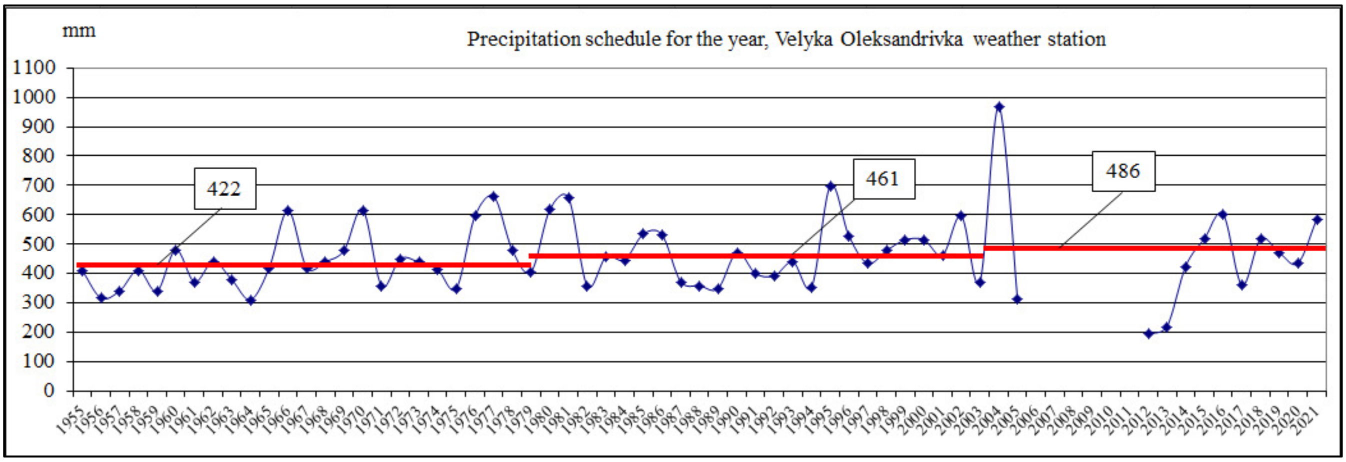

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Fig. 3. Precipitation schedule according to data from the Velyka Oleksandrivka weather station: a) winter period; b) summer period; c) for a year.

Taking into account the conducted analysis and the location of the weather stations, there is reason to say that the significant cause of flooding in the area covered by the weather stations Kherson (western part of Kherson region) and Velyka Oleksandrivka (north-western part of Kherson region) is precisely the natural factor - an increase in atmospheric precipitation. Particular attention should be paid to the increase in the amplitude of precipitation in the summer period in 2005, which exceeds the average value by 360 mm, which was practically not observed in previous years.

Analysis of the multi-year dynamics of precipitation at the Nova Kakhovka and Nizhni Syrogoza weather stations. A comparison of the long-term seasonal irregularity of precipitation at the Nova Kakhovka weather station (Fig. 4) shows an increase in the average annual precipitation from 416 mm in the period 1946-1975 to 420 mm in 1996-2022. Moreover, in the winter period (the most threatening, in terms of the replenishment of groundwater by atmospheric precipitation), the total increase in average precipitation was 14 mm, and in the summer - 24 mm.

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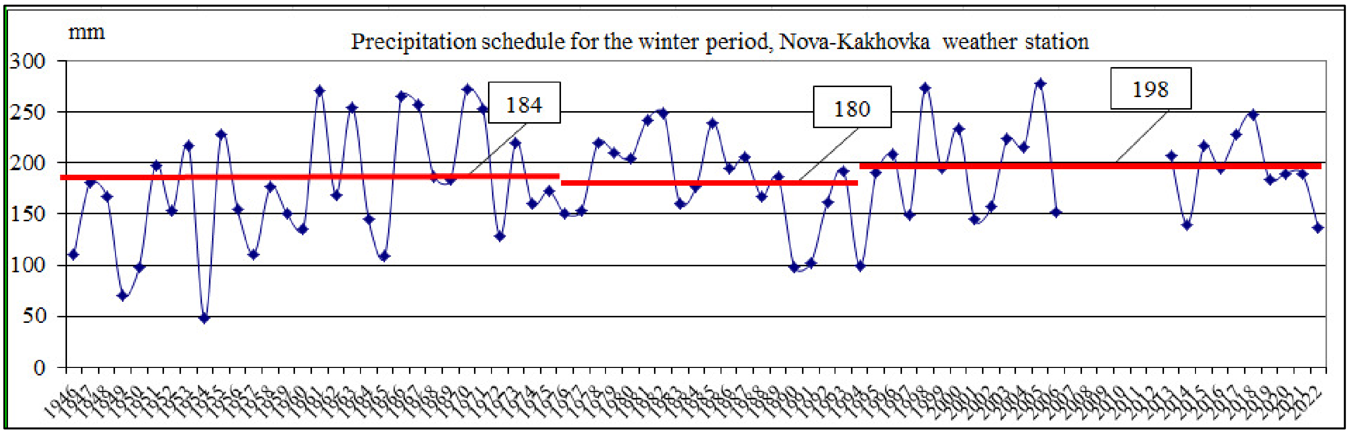

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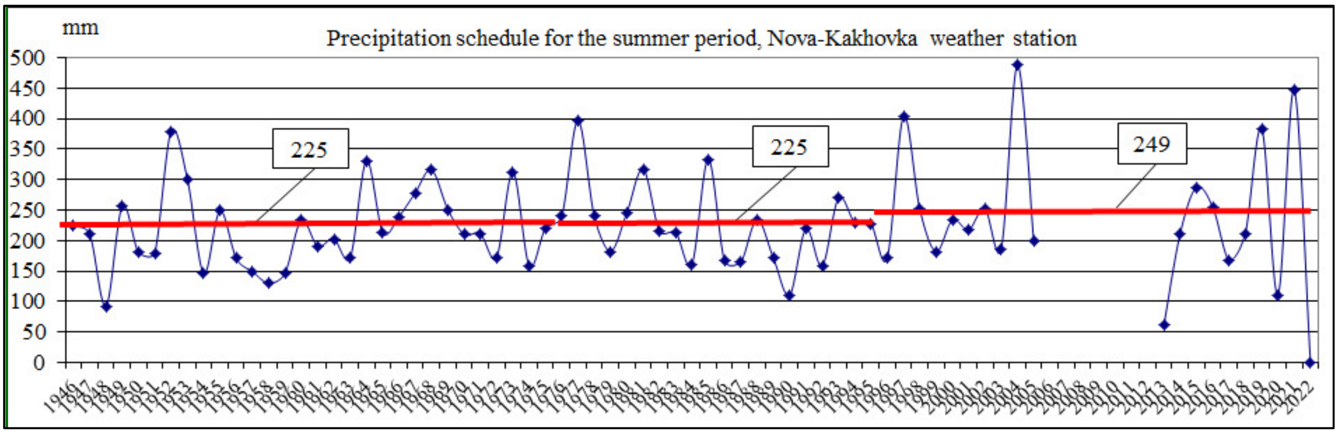

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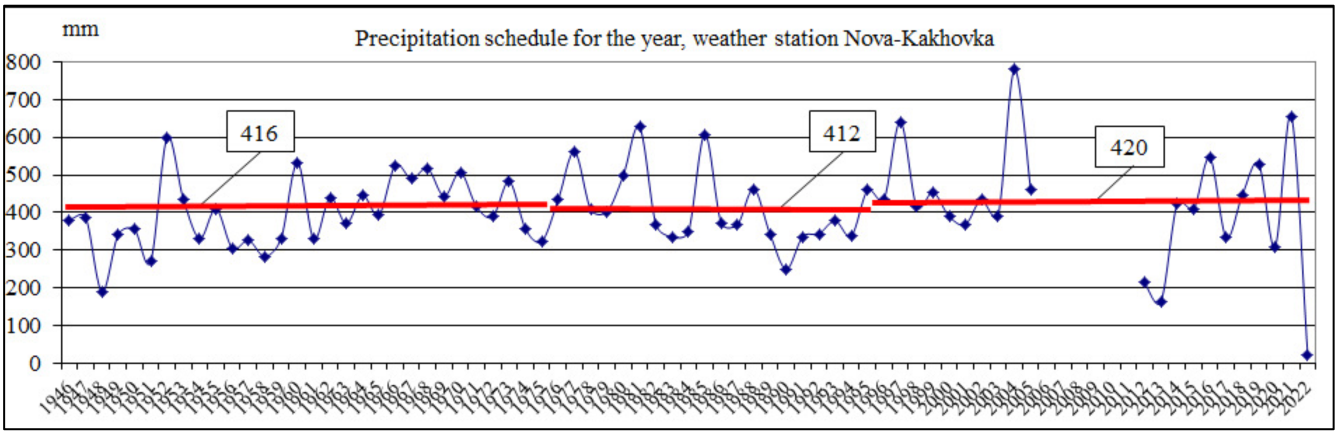

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Fig. 4. Precipitation schedule according to the data of the Nova Kakhovka weather station:
a) winter period; b) summer period; c) for a year.

A comparison of the long-term seasonal unevenness of precipitation according to the data of the Nizhny Sirogoza weather station (Fig. 5) shows a gradual increase in the average amount of precipitation over seventy-five years (98 mm), which indicates a slight increase in the total natural load. Moreover, in the winter period (the most threatening, in terms of replenishment of groundwater by atmospheric precipitation), the total increase in average precipitation was 24 mm, in the summer period the increase was 54 mm.

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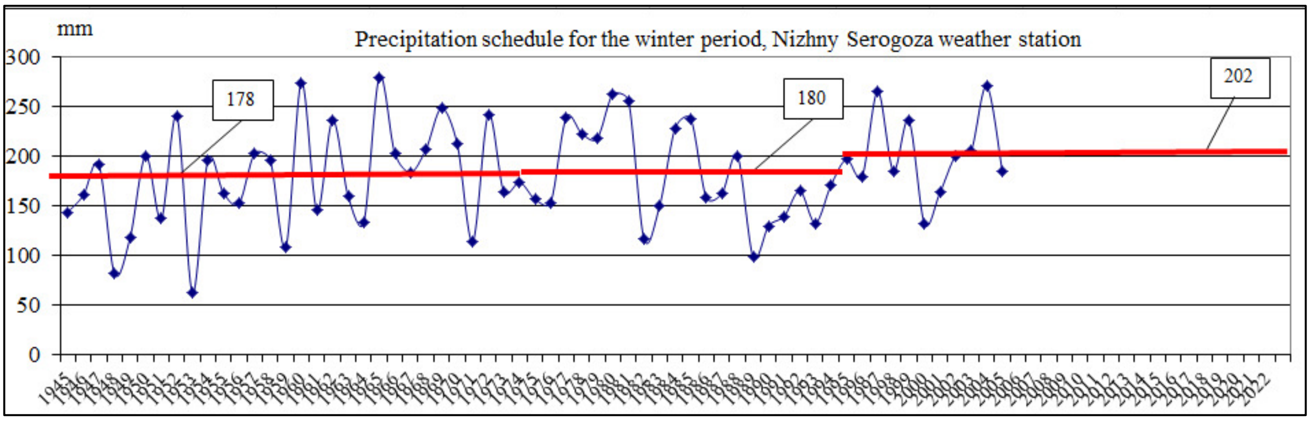

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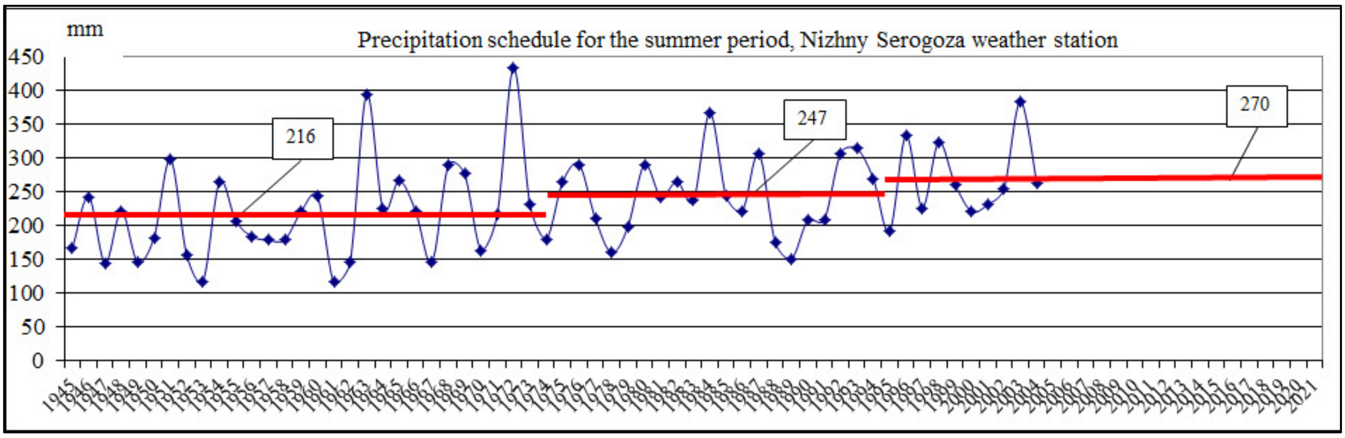

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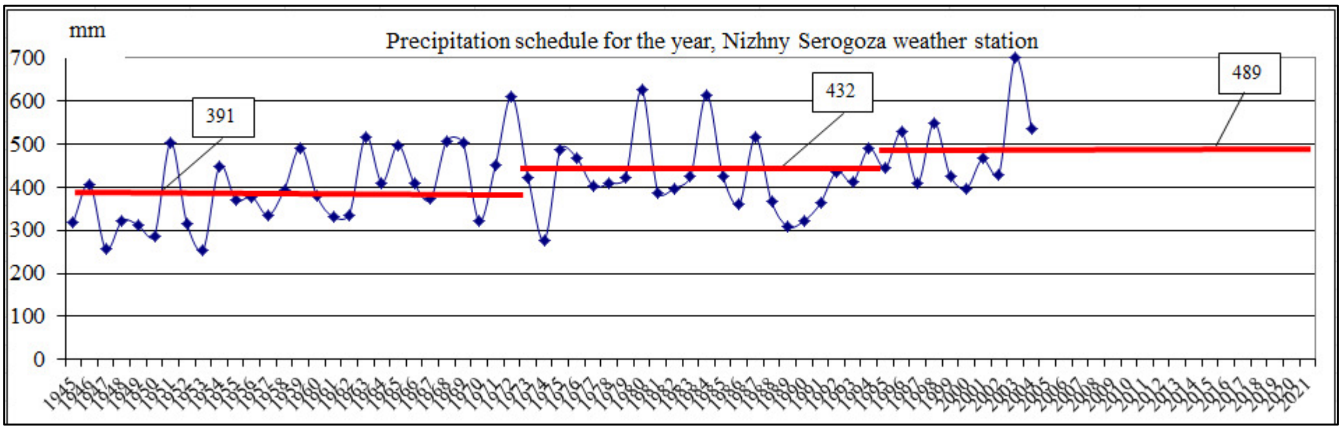

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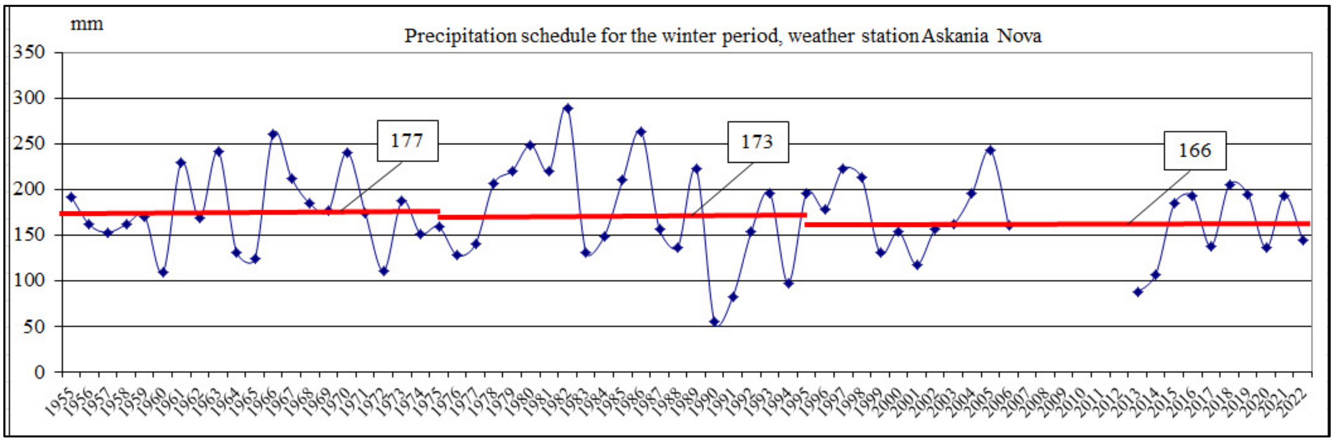
Fig. 5. Precipitation schedule according to the data of the Nizhny Sirogoza weather station:
a) winter period; b) summer period; c) for a year.

Taking into account the conducted analysis and the location of weather stations, there is reason to say that one of the reasons (natural factors) of flooding in the area covered by the Nova Kakhovka and Nizhni Syrogozy weather stations in the recent period (1996 - 2022) is also an increase in atmospheric precipitation. At the same time, the amplitude of precipitation in the summer period in 2005 is increasing, which exceeds the average value by 240 mm, which was practically not observed in previous years.

Analysis of long-term precipitation dynamics of the Askania-Nova and Khorly weather stations. Weather stations Askania-Nova and Nizhny Sirogozy are located in the Kherson region, on the left bank of the Dnipro River.

The analysis of long-term precipitation dynamics was carried out for the following periods: 1955-1975, 1976-1995, 1996-2022.

A comparison of the long-term seasonal unevenness of precipitation according to the data of the Askania-Nova weather station (Fig. 6) shows a slight increase in the average amount of precipitation over twenty years (18 mm), which indicates an increase in the overall atmospheric load. Moreover, in the winter period (the most threatening, in terms of replenishment of groundwater by atmospheric precipitation), there was a slight (11 mm) decrease in average precipitation, in the summer period the increase was 12 mm.



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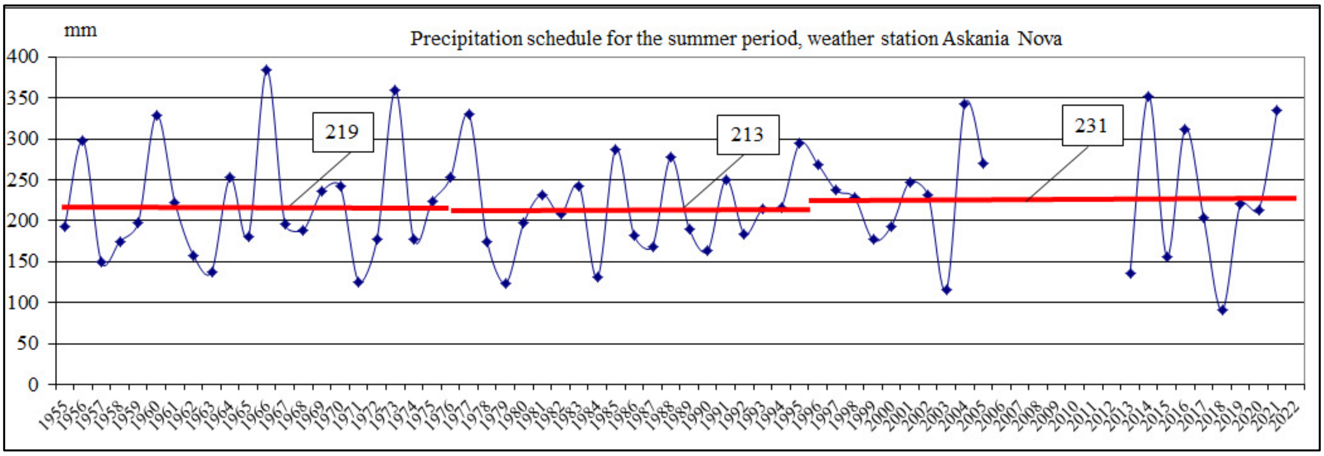

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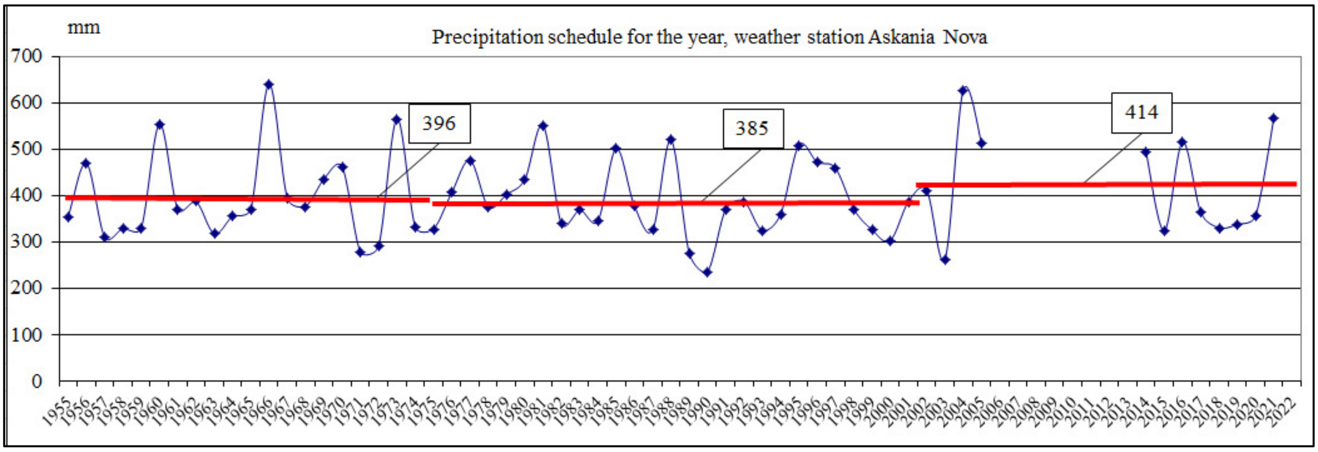

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Fig. 6. . Precipitation schedule according to the data of the Askania-Nova weather station:
a) winter period; b) summer period; c) for a year.

Analyzing the comparison of precipitation according to the data of the Khorla weather station (Fig. 7), we can see that in the period 1976-1995, there was a decrease in the average amount of precipitation for many years by 35 mm. In the last period (1996 - 2022), the reverse process is observed (an increase in the average annual rainfall by 65 mm). Moreover, in the winter period (the most threatening period, in terms of replenishment of groundwater by atmospheric precipitation), the total increase in average precipitation compared to the period 1976-1995 was 34 mm, and in the summer - 15 mm.

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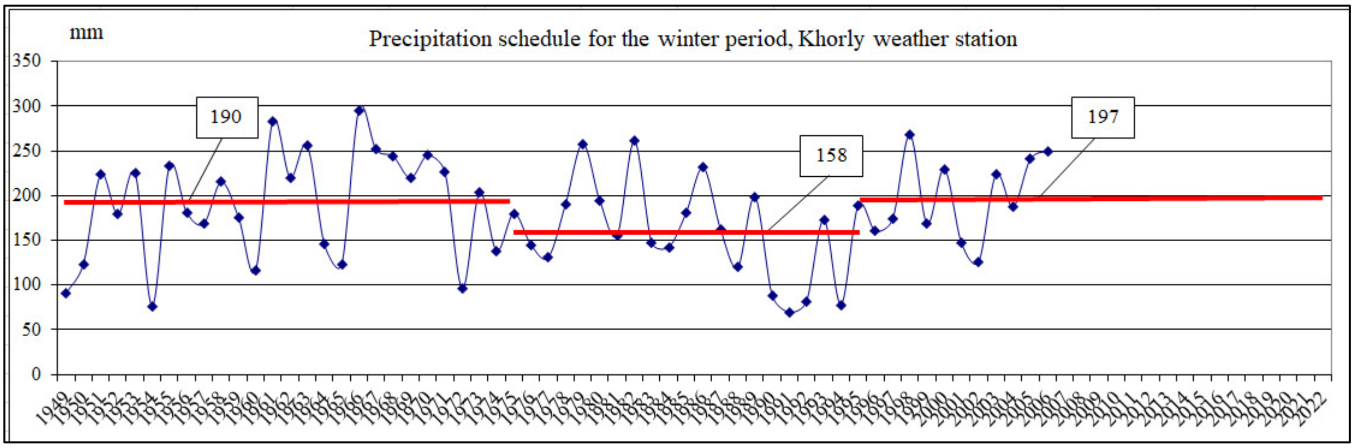

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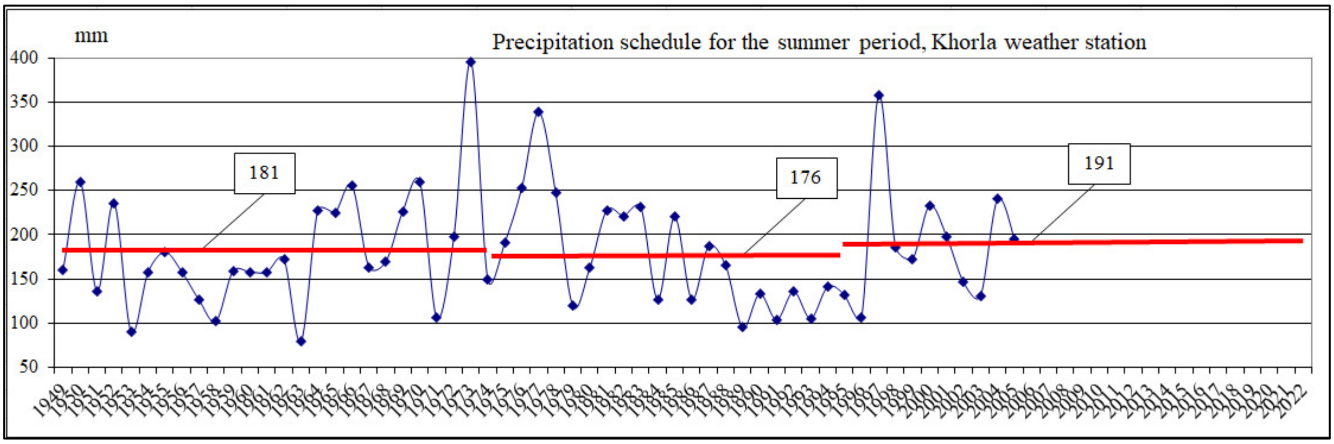

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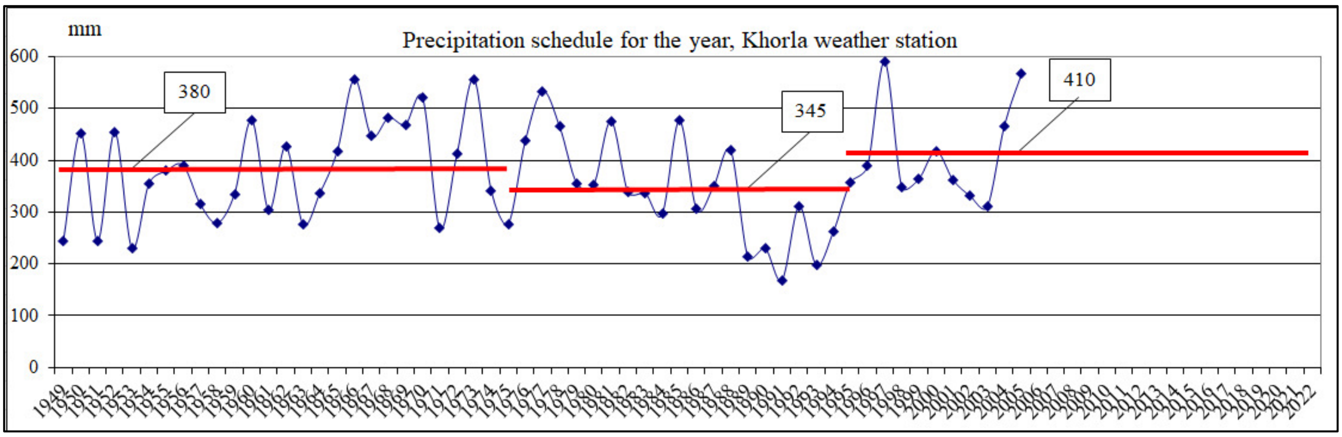

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Fig. 7. Precipitation schedule according to data from the Khorly weather station:
a) winter period; b) summer period; c) for a year.

Taking into account the conducted analysis and the location of the Askania-Nova and Khorly weather stations, there are reasons to say that a small increase in the average amount of precipitation is not able to significantly affect the acceleration of flooding processes in this area.

Conclusions

Long-term analysis of precipitation in the Kherson region indicates an increase in natural load on the right bank of the Dnieper River (weather stations Kherson, Velyka Oleksandrivka) and in the north of the Kherson region (Nova Kakhovka, Nyzhni Sirohozy), which is one of the important natural factors increasing the risk of flooding. At the same time, on the left bank in certain areas (weather stations Askania-Nova, Khorly), there has not been a significant increase in the average amount of precipitation, which suggests the possibility of long-term anthropogenic influence on the flooding process.

Analysis of precipitation showed in some cases an increase in their amplitude in recent years (Kherson weather station 1998, 2004, 2010; Velyka Oleksandrivka weather station 2004, Askania-Nova weather station 2004). This leads to years with an increased risk of flooding and inundation of corresponding areas, as observed in the Kherson region in 1997-1998 and 2004-2005.

Analysis of seasonal unevenness of precipitation revealed an increase in the average amount of precipitation in the winter period over twenty years (Kherson weather station by 33 mm, Velyka Oleksandrivka weather station by 29 mm), which is the most threatening in terms of groundwater replenishment through infiltration.

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